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NEW METHODOLOGIES PROGRAM:
FINAL REPORT

CHARLES W. SIMON
Principal Investigator

Contract No. F44620-76-C-0008
1 September 1975 to 31 October 1977

Prepared for the:
AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Air Force Systems Command
Bolling Air Force Base, Washington, D.C.

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NEW METHODOLOGIES PROGRAM:

FINAL REPORT

1 September 1975 to 31 October 1977

I. INTRODUCTION

This is a Final Report for Contract No. F44620-76-C-0008, "Studies of New Methodologies for Applied Human Factors Research" with Canyon Research Group, Inc., for the period 1 September 1975 to 31 October 1977.

Dr. Charles W. Simon was the Principal Investigator.
Dr. Alfred R. Fregly was Contract Monitor for AFOSR.

II. PROGRAM OBJECTIVES

The objectives to be achieved during this two-year period were: 1) devise strategies for employing "advanced experimental methodologies" developed on this and earlier AFOSR supported programs*; 2) upgrade earlier reports on the basis of the knowledge acquired since their completion; 3) bring together the techniques and strategies into a cohesive document.

* These techniques from earlier programs were summarized in C. W. Simon, Final Report, Advanced Methodologies Study Program, Contract No. F44620-72-C, Culver City, CA: Hughes Aircraft Company, 1 July 1972 to 30 June 1975.

III. SUMMARY OF RESULTS

New Reports

During the period, the following reports were written and published:

Simon, C. W. Response Surface Methodology Revisited: A Commentary on Research Strategy. Westlake Village, CA: Canyon Research Group, Inc., Technical Report No. CWS-01-76, July 1976. (60 pages)

Simon, C. W. Analysis of Human Factors Engineering Experiments: Characteristics, Results and Applications. Westlake Village, CA: Canyon Research Group, Inc., Technical Report CWS-02-76, August 1976. (104 pages)

Simon, C. W. Design, Analysis, and Interpretation of Screening Studies for Human Factors Engineering Research. Westlake Village, CA: Canyon Research Group, Inc., Technical Report No. CWS-03-77, September 1977. (220 pages)

Simon, C. W. New Research Paradigm for Applied Experimental Psychology: A System Approach. Westlake Village, CA: Canyon Research Group, Inc., Technical Report No. CWS-04-77, October 1977. (123 pages)

These reports will be described in the Program Review section below.

Revised Reports

During this period, two reports written on earlier Advanced Methodologies programs for AFOSR were revised:

Simon, C. W. Economical Multifactor Designs for Human Factors Engineering Research. Culver City, CA: Hughes Aircraft Company, TR # P73-326, June 1973.

Simon, C. W. Methods for Handling Sequence Effects in Human Factors Engineering Research, Culver City CA: Hughes Aircraft Company, TR # P74-541, December 1974.

Changes were made on 23 and 21 pages, respectively, and the report numbers were changed by adding the letter "A" to the original number of each. Copies of the revised report were sent to document reference and distribution centers, including DDC, ERIC, NASA-STIF, NTIS, and the Psychological Abstracts.

Seminars

Three more seminars on "Advanced Experimental Methodologies" were given during this period to the following organizations:

Human Factors Laboratory, Naval Training Equipment Center, Orlando, Florida. 15, 16, 17 June 1976.

Studies and Analysis Department, Hughes Aircraft Company, Fullerton, California. 6, 7, 8 July 1976.

Display Systems Department, Hughes Aircraft Company, Culver City, California. October 1976.

Each of these organizations subsequently employed techniques learned from the "Advanced Experimental Methodologies" seminar in their research proposals and/or experiments.

IV. PROGRAM REVIEW

The four reports prepared for this program each make a unique contribution to the objectives cited in Section II. The content of these reports, when properly interpreted and used, should result in a marked improvement in the quality of information obtained from formal psychology experiments. A summary of each report is given below.

1. Analysis of Human Factors Engineering Experiments (CWS-02-76).

Two hundred thirty-nine experiments published in the journal Human Factors during the period from 1958 to 1972 were analyzed for the purpose of discovering the characteristics of their experimental plans, the quality and character of their results, and the degree to which these results had been applied to real systems. The analysis revealed that these experiments investigated too small an experimental space, showed essentially no diversity in their selection of a basic experimental design, collected far more redundant data than was needed, and failed to properly handle the irrelevant variance arising from sequence effects.

When the experimental results were reanalyzed to discover what proportion of the observed performance variance was accounted for by experimental factors, on average, the proportion was much less than half. This proportion increased, on average, as more factors were studied in an experiment although, for any size experiment, there were always some experiments in which the experimental factors accounted for practically none of the observed variance and some in which they accounted for most of it. There was empirical evidence from these experiments to show that third-order or higher interactions had only negligible effects on performance; this was so even though many of these sources had been found to be

"statistically significant." Nearly a quarter of the main effects accounting for less than one percent of the total variance were statistically significant. Subjects used to replicate an experiment (and thus presumed to be homogeneous), generally accounted for much more of the performance variance than specifically selected factors of subject characteristics.

When a survey was made of those who conducted the experiments, it was discovered that slightly more than half of the experiments had been done to find answers of general applicability. Less than a third of the experiments were known or believed to have influenced the design of a real system. A majority of the investigators said they would not do their experiments any differently if they were to repeat them today.

Numerical data in support of these and other results are supplied along with some limited discussion on the implications of this analysis for an improved experimental methodology. This represents, it is believed, the first extensive collection of "hard" data on these topics.

2. Response Surface Methodology Revisited. (CWS-01-76)

This report critically evaluates a series of five published papers that purported to explain and illustrate the characteristics and applications of central-composite designs (CCDs) in the context of response-surface methodology (RSM). The series was important because it succeeded in arousing among human factors investigators considerable interest in this powerful experimental methodology. A detailed evaluation revealed, however, that the experimental papers in that series 1) fail to illustrate the most important and useful features of "response surface methodology" designs as proposed by G.E.P. Box and his associates; 2) employ questionable procedures not

specific to RSM that permit interpretations of results not considered by the investigators; and 3) do not constitute an experimental evaluation of the effectiveness of RSM central-composite designs as suggested by the investigators. Because the published experiments were being used as models of good research employing this methodology, which they were not, this report was written to alert potential users to their weaknesses, as they affected both application and interpretation, and to offer constructive guidance. The distinction between using an experimental design, that is, a pattern of data-collection points, and employing an experimental strategy is emphasized.

3. Design and Analysis of Screening Studies. (CWS-03-77)

In this report, methods are described for constructing Resolution IV screening designs that are robust to linear, quadratic, and cubic trend effects and will also keep the number of factor-level changes for some variables at a minimum. Complete designs, capable of screening up to 32 variables, are provided along with appropriate methods of analysis. Numerous criteria for selecting non-trivial variables are discussed, including: mean difference, eta squared, cumulative probability, and half-normal plots. How to handle subjects in an experiment is described when their characteristics can be included as experimental factors and when they cannot be, and when subjects are merely a form of replication. The values of introducing multiple center points into the 2^{k-p} fractional factorial screening designs are discussed, particularly as they are used to build the screening design into a central-composite design. Lack-of-fit tests are provided to help decide whether a second- or a third-order response surface is needed. Numerous methods of analyzing screening studies with multiple responses are described. A method is given for developing a prediction equation with data collected from an incompleted screening design.

4. New Research Paradigm for Experimental Psychology. (CWS-04-77)

To spotlight the crisis occurring in scientific psychology, warnings, complaints, and criticisms by prominent psychologists and non-psychologists are quoted. Traditional experimental method of the past hundred years does not produce the data needed to solve problems faced by a modern society. The results from many experiments cannot be combined into a modular, quantitative data base.

The traditional experimental method, as it is applied in engineering psychology, is critically examined. Characteristic procedures and concepts are analyzed to show why they have been counterproductive to the ultimate experimental goals -- prediction of field performance and aggregation of data for future use.

The two distinct approaches to data collection used by empirical psychologists, "Experimental" and "Correlational," are defined and compared. Arguments are presented for merging the more productive features of each. However, contrary to suggestions in the past, the combined approach would emphasize the point of view of the Experimentalists. This means that the manipulative method would be retained but in a way that would enable the holistic philosophy of the Correlationists to dominate.

Philosophy, strategy, and techniques are described that can be combined into a new research paradigm for experimental psychology. A sequential process is proposed that enables systematic multifactor experiments to be performed with great economy. Problems are first defined with a real-world orientation. Next, using primarily manipulative procedures, fifty to one-hundred candidate factors from equipment, environment, personnel, and task sources, can be screened systematically to

identify the non-trivial ones. These non-trivial factors for the particular task are then subjected to further investigation, the data from which being combined with that from the screening study to produce a response surface as defined by a polynomial of the appropriate degree. This equation is then refined, minimizing both bias and random error, the fiducial limits determined, and the resulting product verified under operational conditions. Further refinement may be required.

The feature that makes this paradigm unique is that the total data-collection process for deriving an equation of all critical variables affecting an operational task will ordinarily be less than that used in four and five factor experiments using traditional methodology. The consequences are that prediction from laboratory data to field performance becomes a reality and a quantitative data base for future reference can be constructed.

V. CONCLUSIONS

Not only were the objectives of the immediate program met during this period, but also some of the long-range objectives set seven years ago at the beginning of the Advanced Methodologies Program, and those of the Principal Investigator set twenty-five years ago. It is now possible to systematically study the effects of twenty-five, fifty, or even one-hundred variables deemed potentially critical to a particular task, and to do so with considerable economy in the data-collection effort while meeting all relevant scientific standards. No practical technique has ever been available before that would permit the experimental psychologist to investigate problems of such complexity in such a systematic and economical manner. The paradigm for this is described in one of the reports completed this year.

Two conditions, however, mar the conclusiveness of this success. One, the paradigm is uneven in the detail in which it has been worked out. This must be corrected to facilitate its use. Until that time, an investigator who wants to apply the method must be prepared to smooth these gaps himself. Two, efforts to date to apply the paradigm have shown evidence of faulty designs, incomplete analyses, and erroneous interpretations. These have not been due to any inadequacy in the paradigm or methodologies involved, but instead have reflected inadequate preparation on the part of investigators before they begin their experiments. In spite of all this, the response to the total program has been positive enough, particularly by the small group who have read the reports and attended the seminars, to conclude with great confidence that this new approach to experimental psychology will survive and flourish.

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- Simon, C. W. Reducing irrelevant variance through the use of blocked experimental designs. Culver City, CA: Hughes Aircraft Co., Tech. Rep. No. AFOSR-70-5, November 1970a, 65 pp.
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- Simon, C. W. Response surface methodology revisited: a commentary on research strategy. Westlake Village, CA: Canyon Research Group, Inc., Tech. Rep. No. CWS-01-76, July 1976a, 60 pp.
- Simon, C. W. Analysis of human factors engineering experiments: characteristics, results and applications. Westlake Village, CA: Canyon Research Group, Inc., Tech. Rep. No. CWS-02-76, August 1976b, 104 pp.
- Simon, C. W. Design, analysis, and interpretation of screening designs for human factors engineering research. Westlake Village, CA: Canyon Research Group, Inc., Tech. Rep. No. CWS-03-77, September 1977, 220 pp.

"SEMINARS ON "ADVANCED EXPERIMENTAL METHODOLOGIES"

California State Psychological Association (Annual Convention),
Anaheim, California. 6 March 1975.

Flying Training Division, Williams Air Force Base, Phoenix,
Arizona. 23-24 April 1975.

Aerospace Medical Research Laboratories, Wright-Patterson
Air Force Base, Dayton, Ohio. 10-11 June 1975.

Weapons Development Department, Naval Weapons Center, China
Lake, California. 28, 29, 30 October 1975.

Human Factors Laboratory, Naval Training Equipment Center,
Orlando, Florida. 15, 16, 17 June 1976.

Studies and Analysis Department, Hughes Aircraft Company,
Fullerton, California. 6, 7, 8 July 1976.

Display Systems Department, Hughes Aircraft Company, Culver
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